SMALL- AND LARGE-CRACK DAMAGE-TOLERANT DATABASES FOR ROTORCRAFT MATERIALS

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Federal Aviation Administration
William J. Hughes Technical Center
Atlantic City International Airport
New Jersey

SMALL- AND LARGE-CRACK DAMAGE-TOLERANT DATABASES FOR ROTORCRAFT MATERIALS

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EXPENDITURES (as of January 31, 2007)

	Budget	Expended	Available
FAA	50,000	32,474	17,526
Salaries	18,674	7,312	11,362
Fringe	3,146	423	2,723
Tuition	2,880	1,429	1,451
Travel	1,558	0	1,558
Contractual	7,825	0	7,825
Equipment	2,500	22,747(a,b)	(20,247)
Indirect	13,417	563	12,854
Total	50,000	32,474	17,526

(a) Pump for the two (2) new test machines installed Dec 2006
(b) Pending budget revision approval

CRITICAL ISSUES AND CONCERNS

- A pump failure has required that all available funds allocated for equipment during the 4-year project had to be moved to the first year.
- Identification of a “low-strength” rotorcraft steel, which may exhibit severe threshold fanning with stress ratio (like low-strength 4340 steel) has not been found.

PROJECT OBJECTIVES

- Test a number of materials of interest to the rotorcraft industry using both bend- and tension-loaded large-crack specimens (two aluminum alloys, one titanium alloy, and low-strength steel)
- Test the same materials with small surface cracks under tension in a plate with micro-notches or at a hole with naturally-initiated cracks at microstructural features under tension and/or bending
- Establish material databases from threshold to fracture using the new compression pre-cracking threshold test methods to help resolve the issue of transferability of crack-growth data from laboratory specimens to rotorcraft structures
- Validate a database and the crack-growth methodologies on a complex simulated rotorcraft (non-proprietary) component with consultation with a rotorcraft company

SCOPE OF RESEARCH WORK

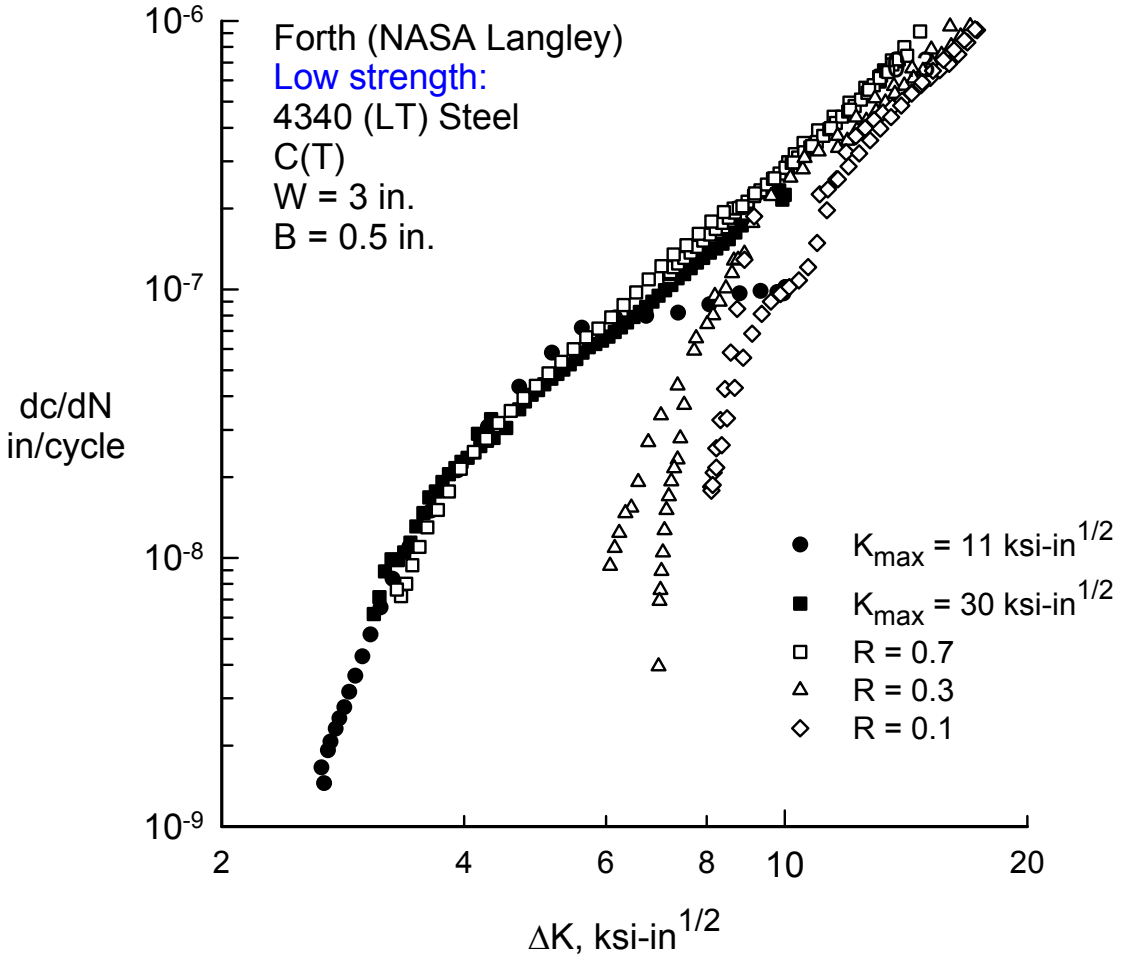
- Small-crack testing on a variety of materials
- Large-crack testing from threshold to fracture
- Develop damage-tolerance databases
- Validate fracture mechanics concept of transferability from laboratory specimens to complex rotorcraft structures
- Transfer databases to rotorcraft industry and to the developers of NASGRO and AFGROW

CANDIDATE MATERIALS

- Aluminum alloy 2024-T3 (and 7075-T6)
- Aluminum alloy 7050-T7451
- Titanium alloy Ti-6Al-4V (β-STOA)
- Steel (TBD, 4340, 9310, D6ac, etc.)
- Others materials of interest

Issue on Low-Strength Steels (HY-80, 4340, D6ac)

Low-strength steels tend to exhibit severe threshold fanning with the stress ratio (R).



Possible reasons:

- **Load history (plasticity effects)**
- **Environmental (oxide debris)**
- **Configuration (T-stress)**
- **Roughness ? (very flat surfaces)**

Task Schedule – Years 1 and 2

FAA-Database		Year 1												Year 2											
		O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Task ID	Task Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	Literature survey on small-crack measurement methods																								
2	Literature survey on fatigue-crack-growth-rate data																								
3	Stress analysis on large-crack specimen design																								
4	Stress analysis on small-crack specimen design																								
5	Procure 2024 alloy from NASA and machine specimens																								
6	Contact Sikorsky for Ti-6Al-4V (β) and machine specimens																								
7	Contact Bell Helicopter for 7050 alloy & machine specimens																								
8	Contact Boeing for TBD steel & machine specimens																								
9	Develop CMOD or BFS equations for proposed specimens																								
10	Develop K and T-stress equations for proposed specimens																								
11	First annual report and review of project																								
12	Conduct FCG tests on C(T) specimens for 2024-T3 alloy																								
13	Conduct FCG tests on SM(T) specimens for 2024-T3 alloy																								
14	Compare small- and large-crack data on 2024-T3 alloy																								
15	Conduct FCG tests on SM(T) specimens for Ti-6Al-4V alloy																								
16	Second annual report and review of project																								

(1) Literature Survey on Small-Crack Testing

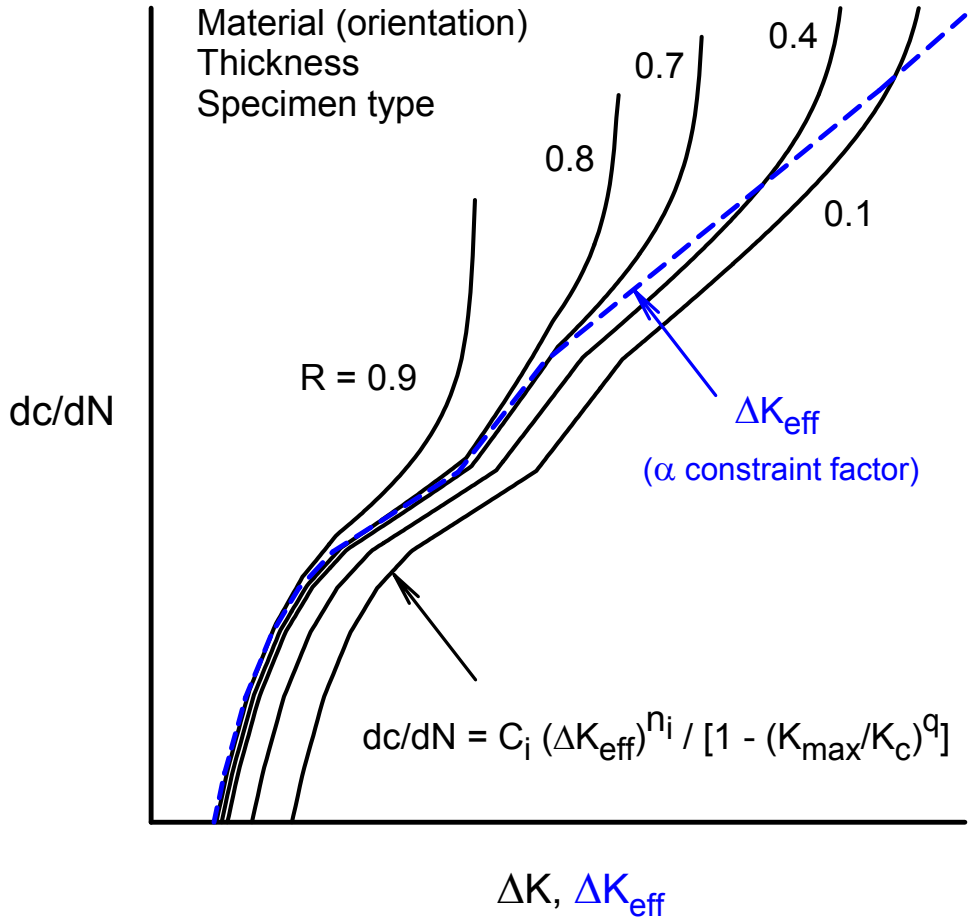
Accomplishment: A report on the current state-of-the-art on small-crack testing, measurement methods, and the analyses methods that have been developed to model small-crack behavior is in progress.

An assessment was made on small-crack specimens, the most reliable and economical method to use at MSU to monitor small-crack growth, and what improvements have been made in the analysis of small cracks.

FASTRAN models small-crack behavior from plasticity and crack-closure transients, and micro-structural effects are in the measured crack-growth-rate behavior.

(2) Literature Survey on Fatigue-Crack-Growth Data

<u>Accomplishment</u>: Literature data sets have been obtained from the NASGRO database on the materials to be tested and analyzed in the current project.

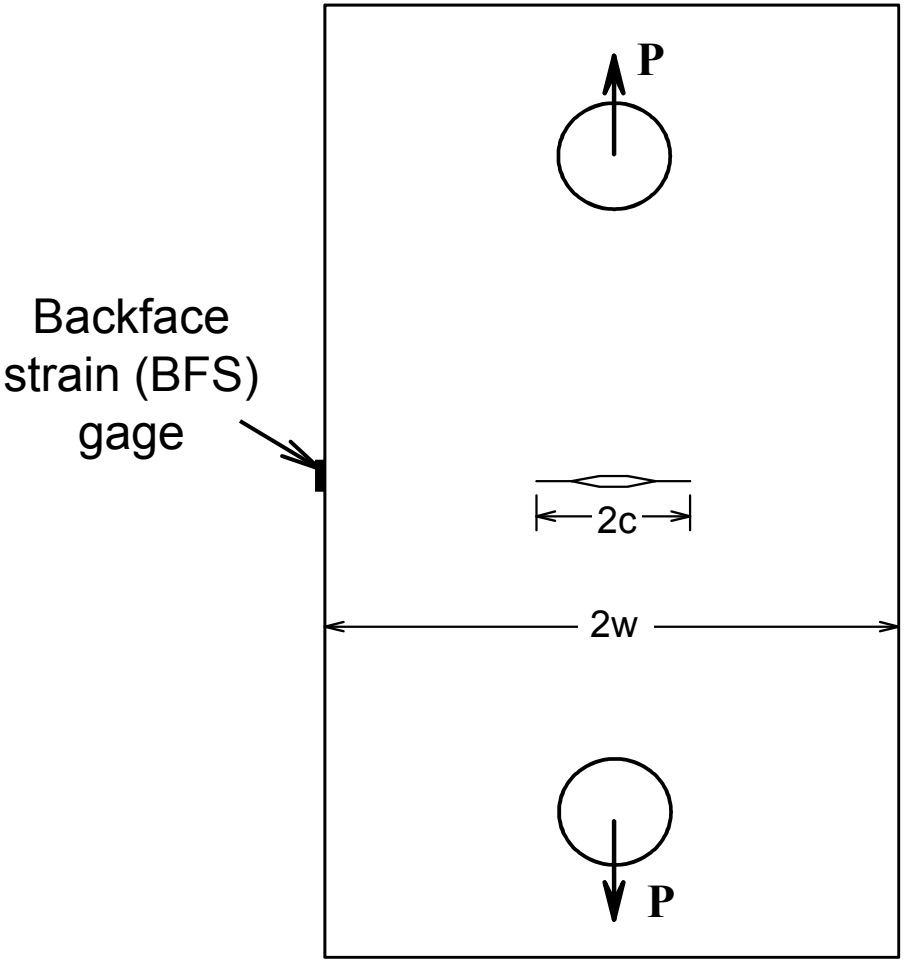


<u>Candidate materials:</u>

- **Al 2024-T3**
- **Al 7075-T6**
- **Al 7050-T7451**
- **Ti-6Al-4V (β-STOA)**
- **Steels:**
  - **4340**
  - **9310**
  - **D6ac**
- **Others of interest**

(3) Stress Analysis of Large-Crack Specimen

R. Forman, NASA JSC



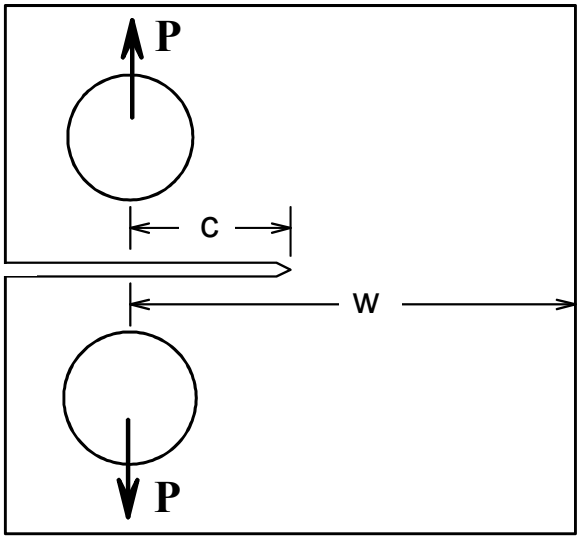
Short-Middle-Crack-Tension SM(T)

Monitor crack growth:

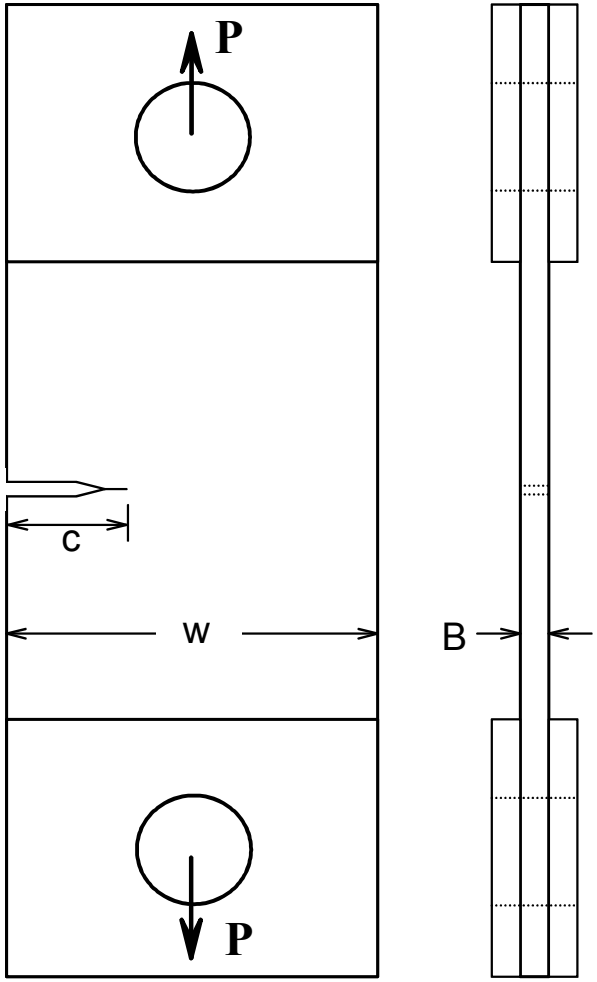
- Krack® gage
- CMOD gage
- BFS gage

(3) Stress Analysis of Large-Crack Specimen (cont.)

Accomplishment: A wide variety of candidate specimens have been analyzed to find a specimen that will allow the usage of the BFS gage concept for monitoring crack growth.

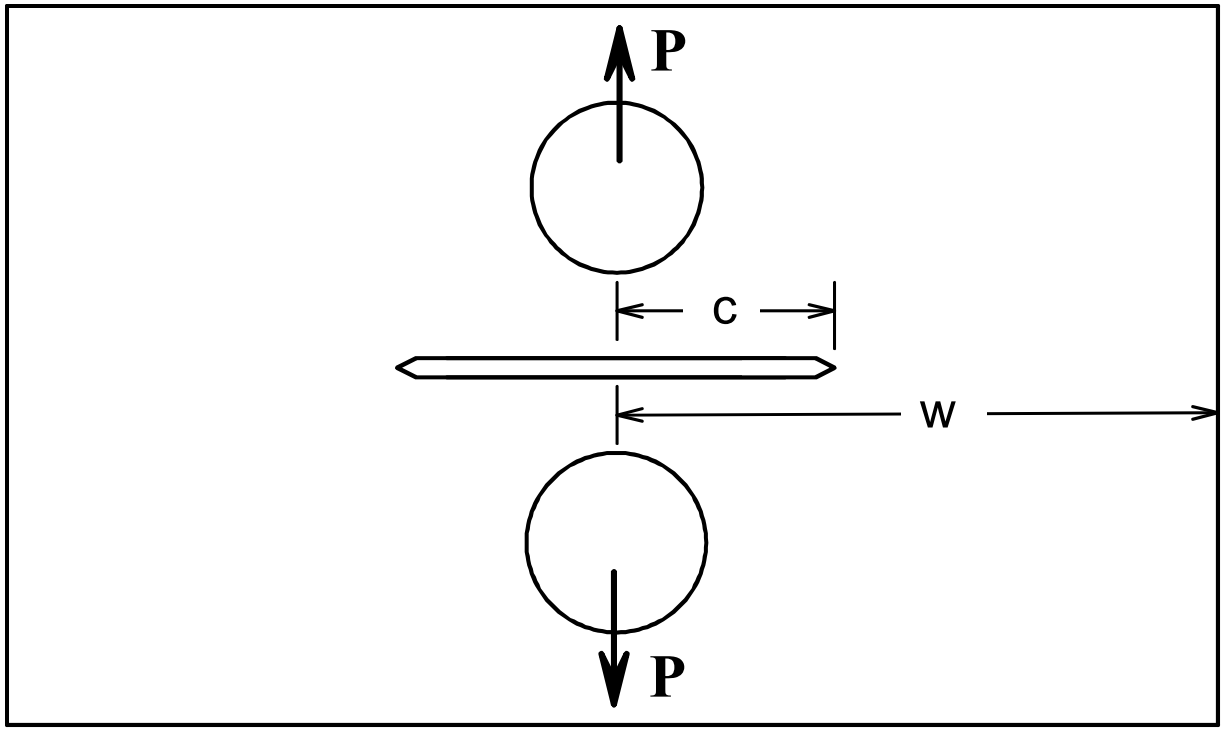


Compact C(T)



Single-edge-crack tension SE(T)

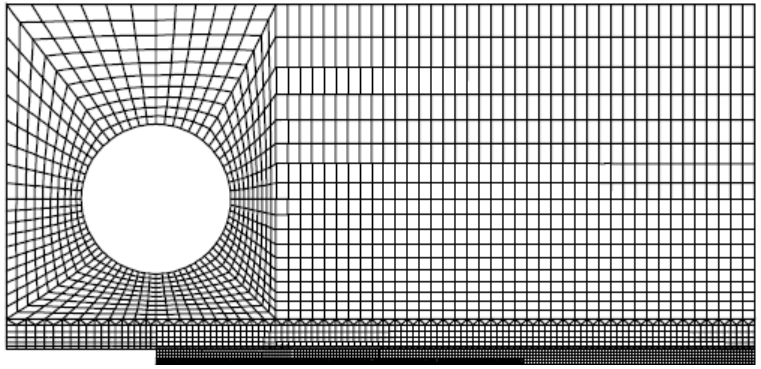
Some Other Crack Configurations Analyzed



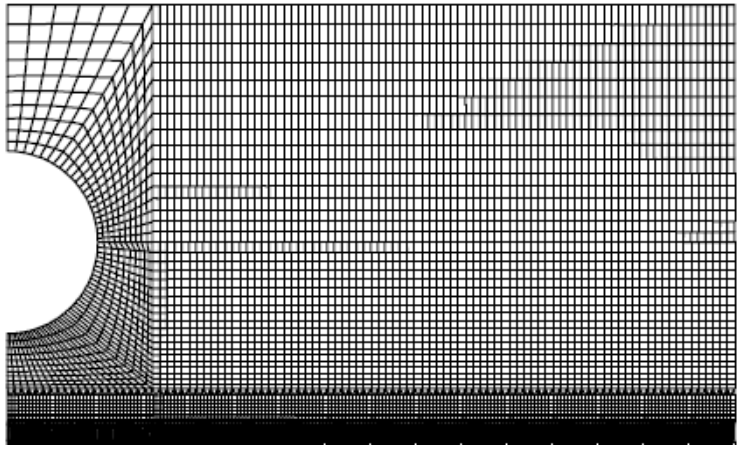
Double Compact

Typical Finite-Element Meshes for Crack Specimens

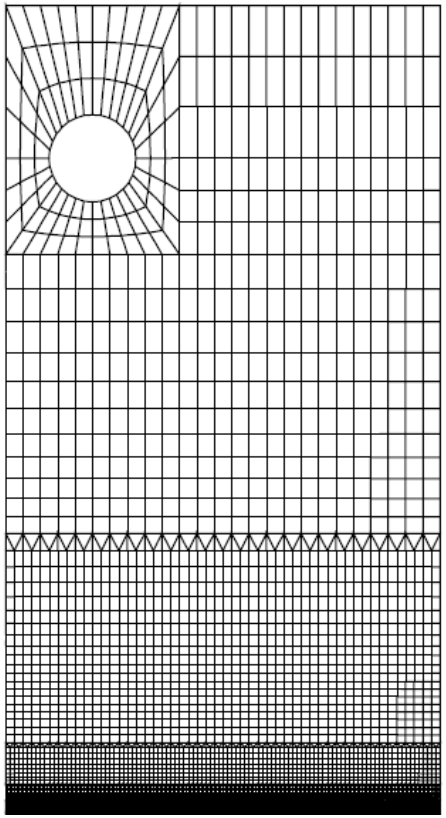
FRANC2D Analysis Code (Cornell University)



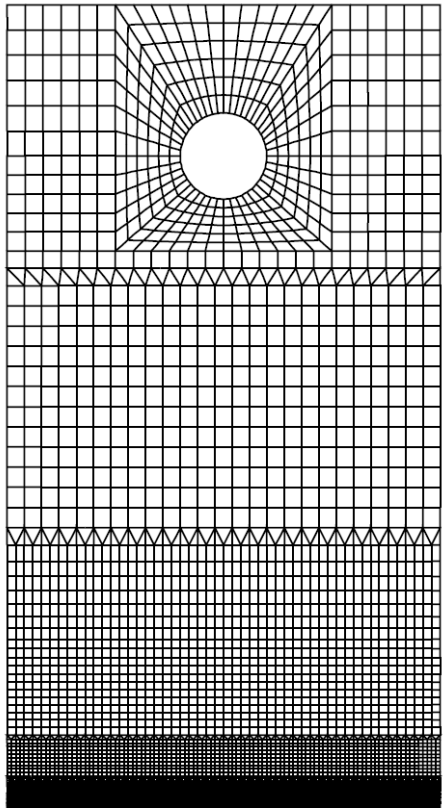
(a) Compact (7,000 elements)



(b) Double Compact (20,000 elements)

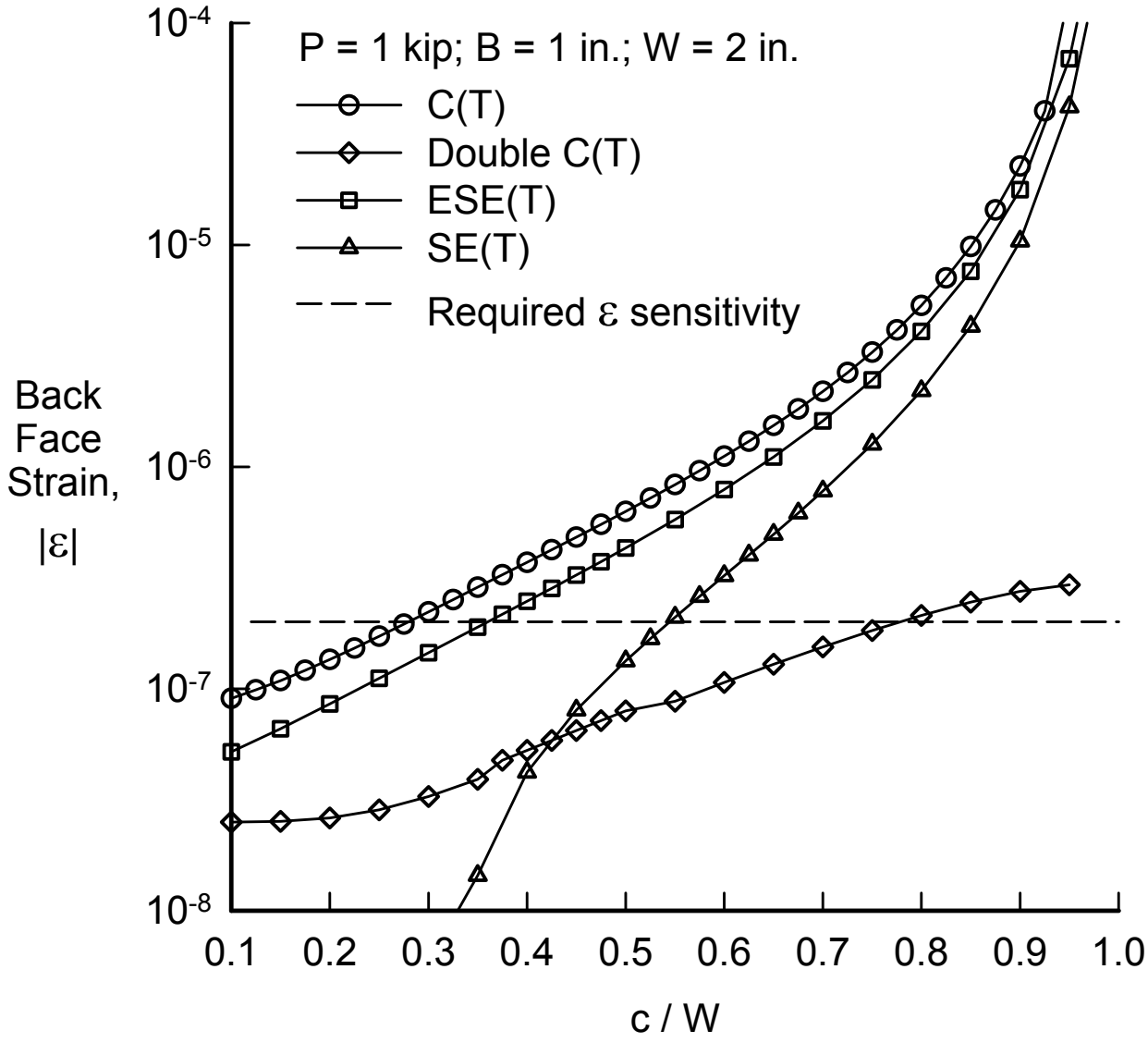


(c) ESE(T) (18,000 elements)

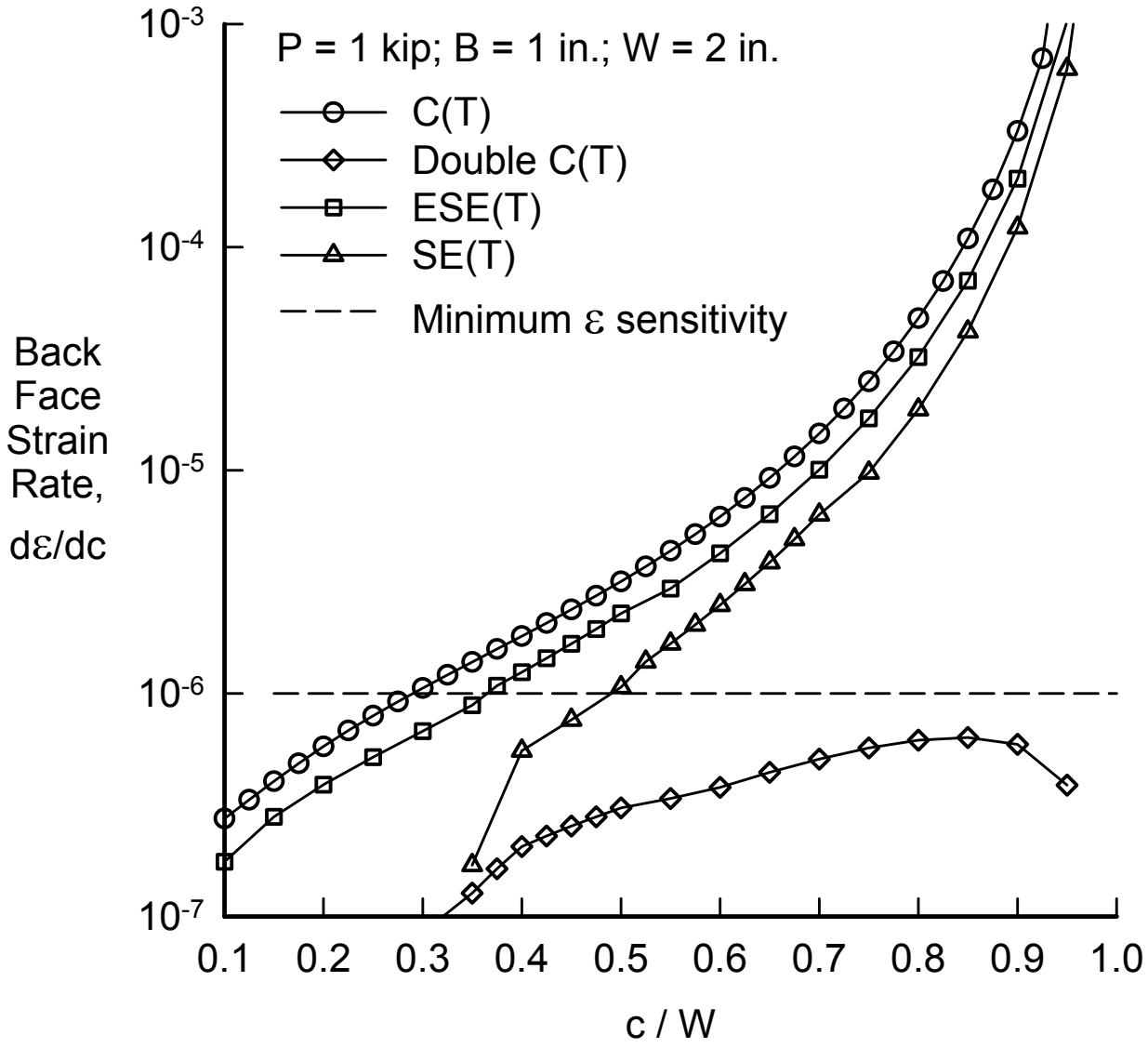


(d) SE(T) (18,000 elements)

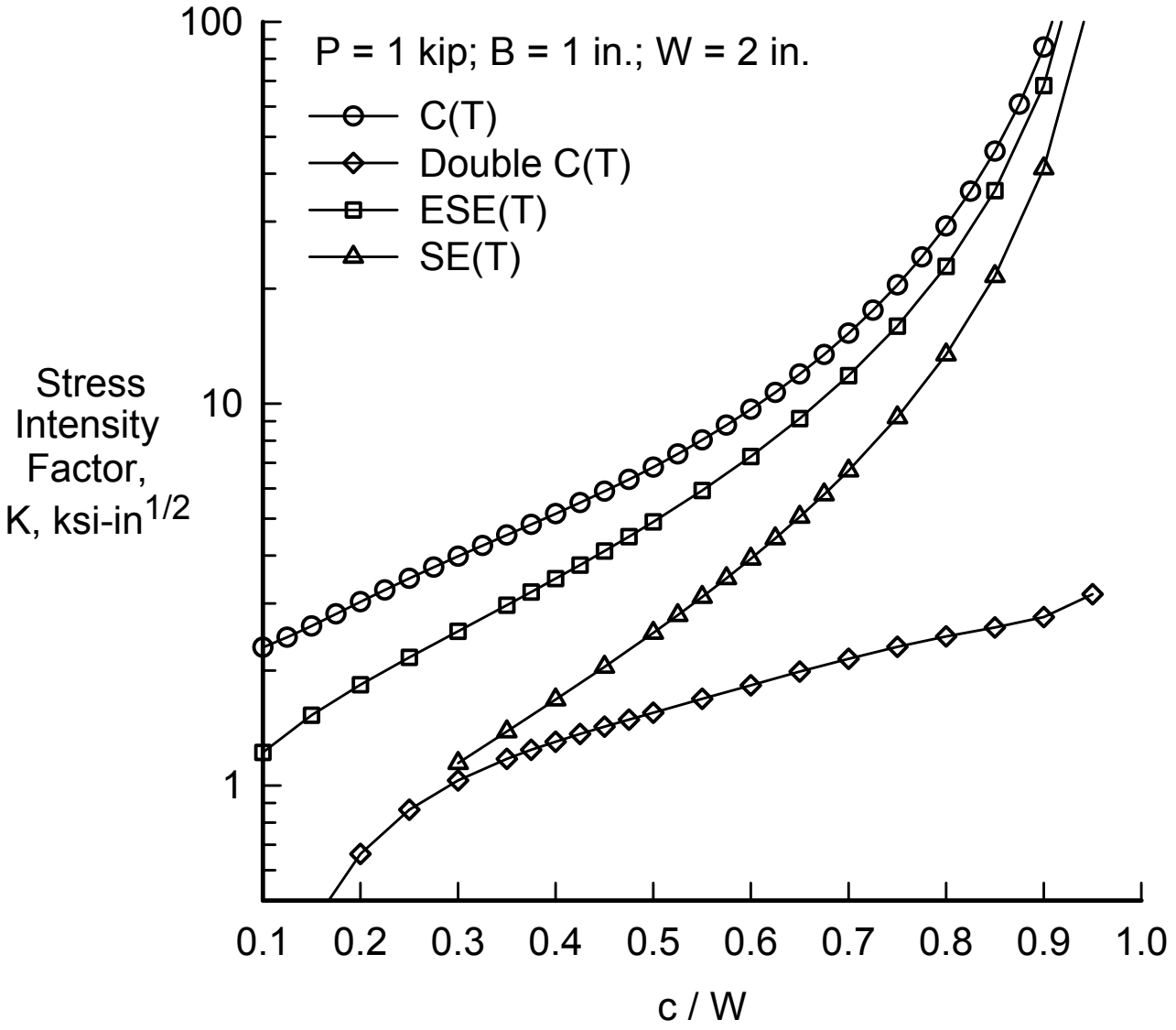
BFS Analyses of Various Crack Configurations (1)



BFS Analyses of Various Crack Configurations (2)



SIF Analyses of Various Crack Configurations



(4) Stress Analysis on Small-Crack Specimen

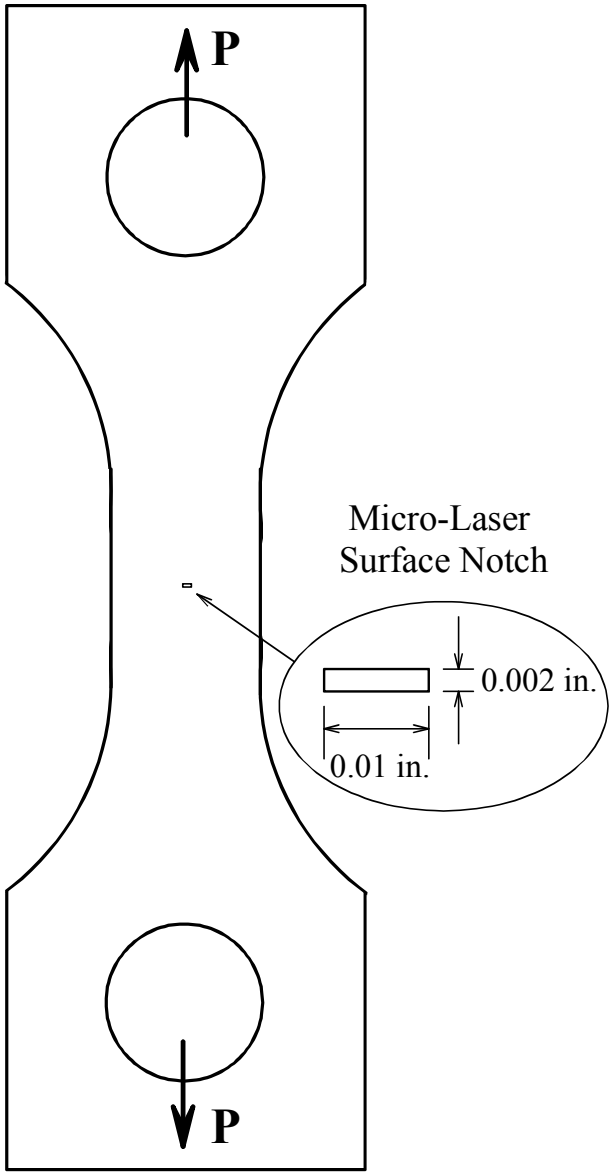
Accomplishment: Develop a small-crack test specimen design that would use either micro-notches or naturally initiated cracks to develop surface-crack growth data for each material tested (in progress).

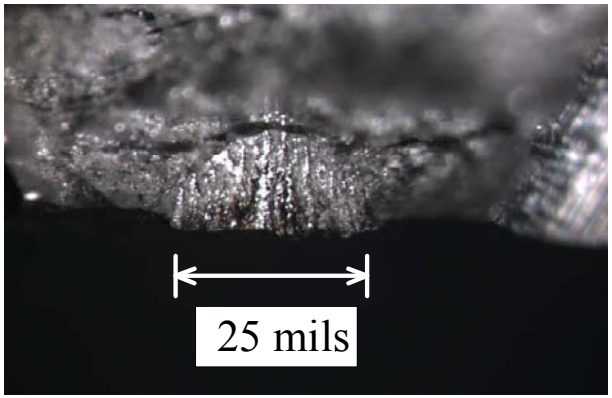
Options:

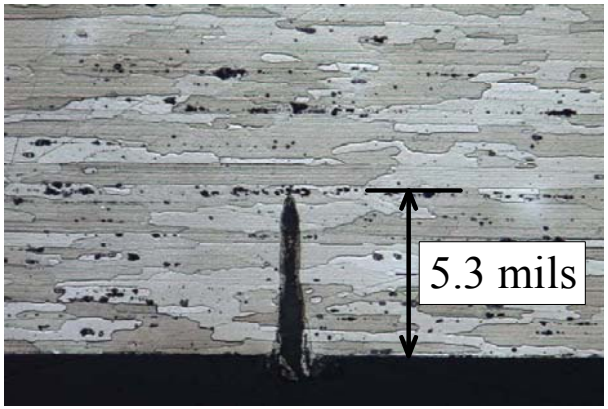
(1) Small surface crack from micro-notch under tension

(2) Naturally-initiated small cracks from material micro-structure at a semi-circular-edge-notch under tension and/or bending loads

Surface-Crack Specimen with Micro-Laser Notch

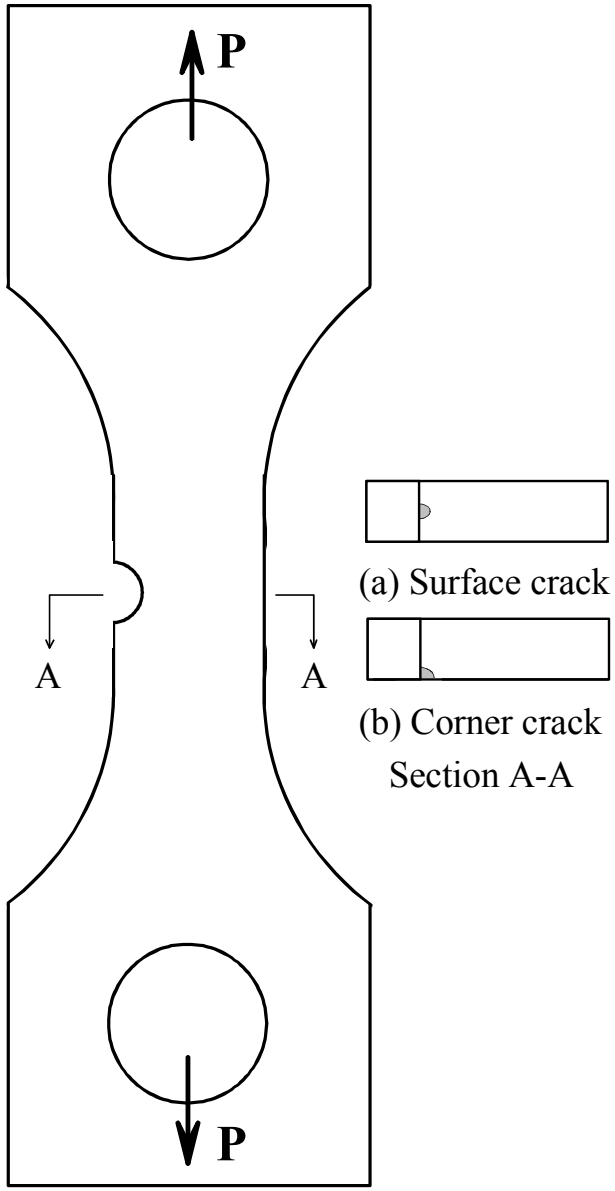






S. Smith, Hamilton-Sundstrand

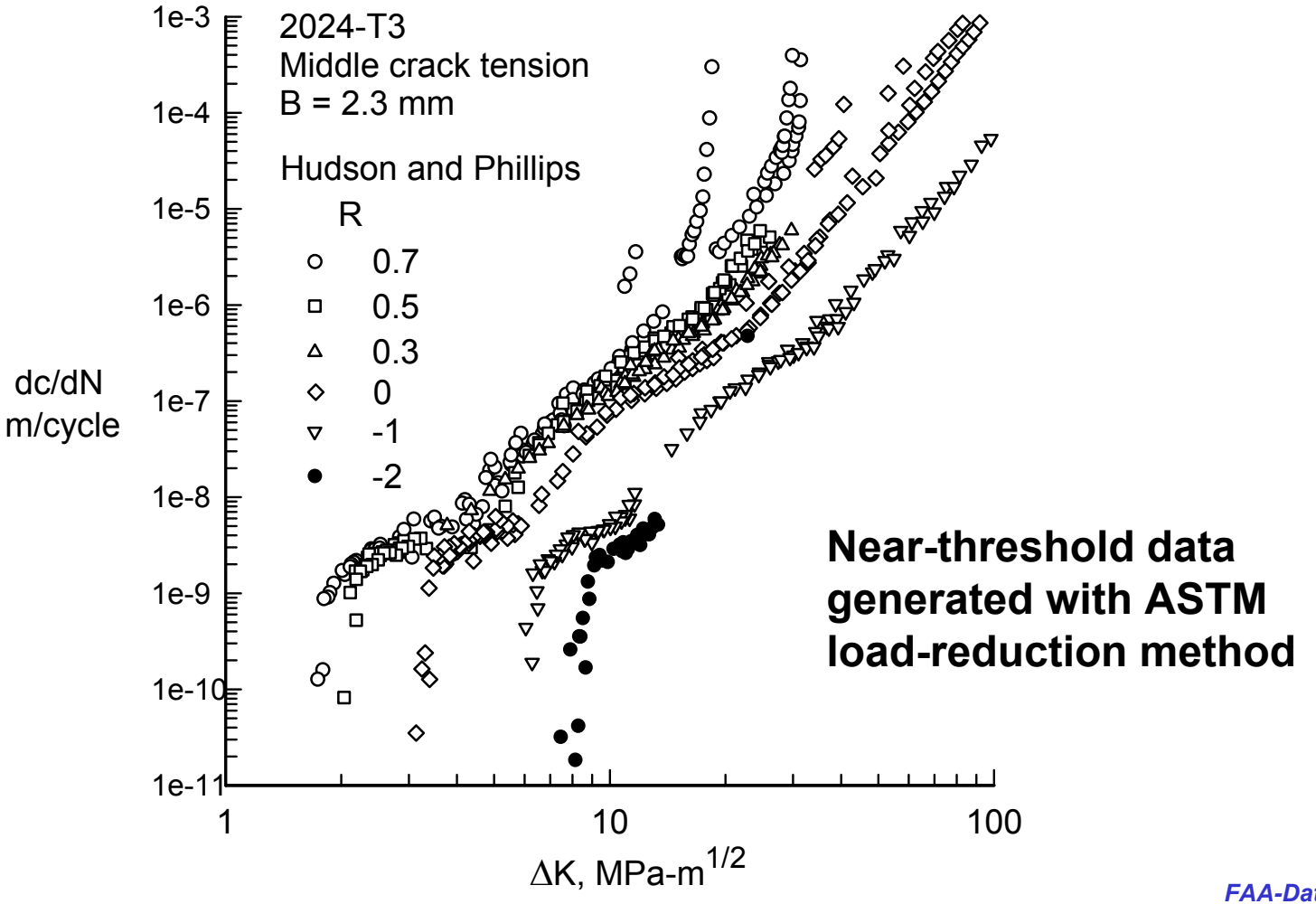
Single-Edge-Notch Small-Crack Specimen



- Modeled after the AGARD & NASA/CAE small-crack specimen
- Generate S-N curves at several stress (R) ratios
- Monitoring small-crack growth:
  - Photographic
  - Plastic-acetate replica
  - Repliset® replica
  - Hot glue (NGC)
- Novel method to generate SIF solutions for small surface and corner cracks

(5) Procure 2024 Material from NASA Langley

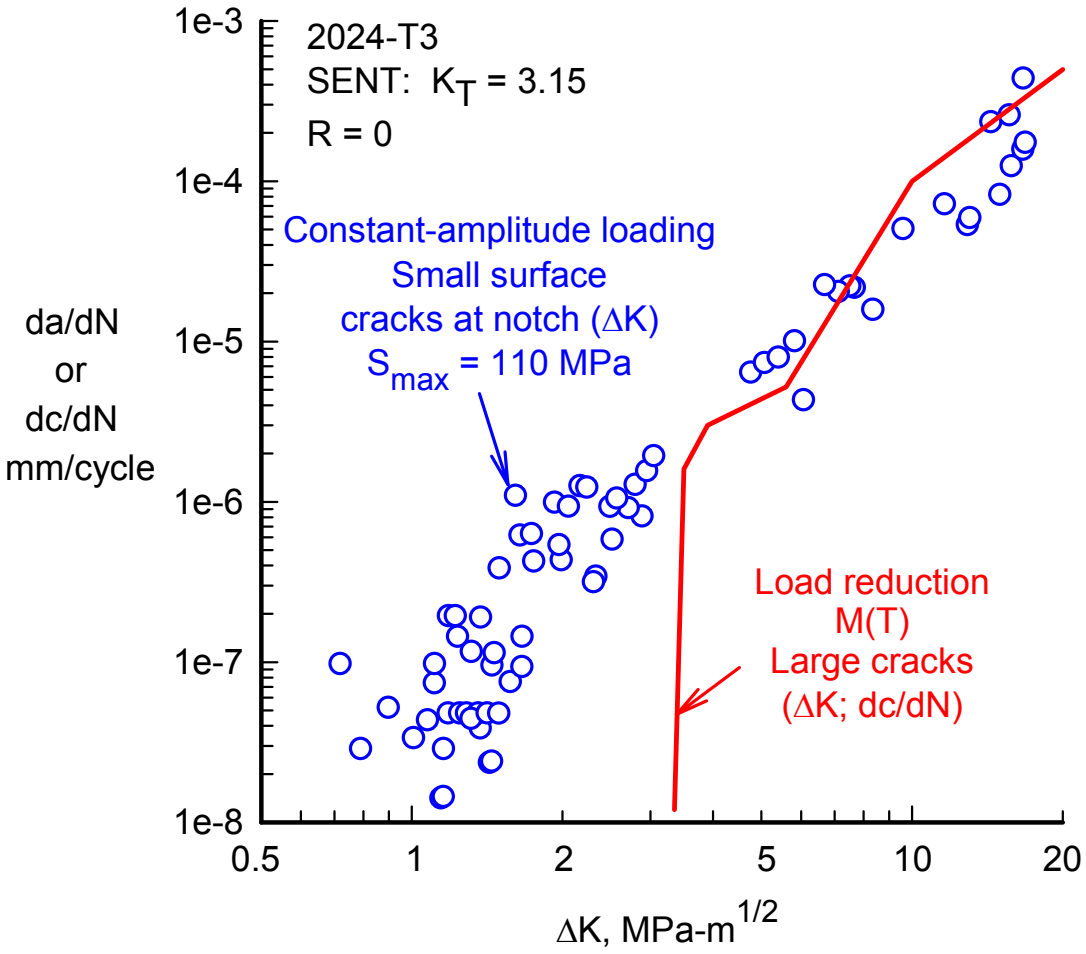
Accomplishment: Material (2024-T3 & 7075-T6 sheets; B = 2.3 mm) have been obtained from NASA LaRC.



Near-threshold data generated with ASTM load-reduction method

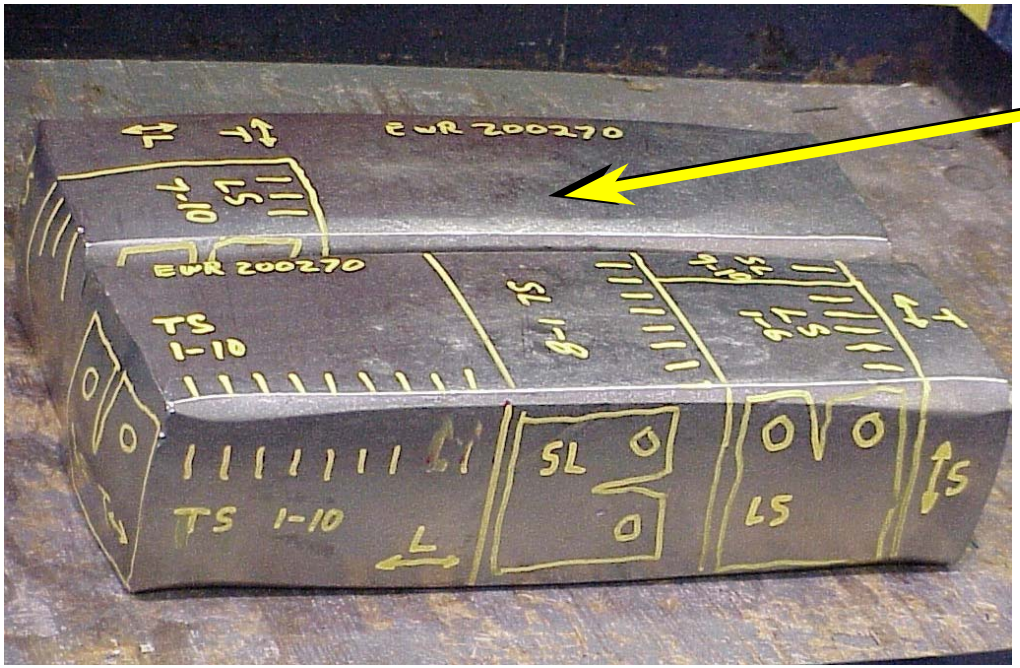
Issue on Small- and Large-Crack Data for 2024-T3

The 2024-T3 small- and large-crack data shows a very large difference in the near-threshold regime.



(6) Contact Sikorsky for Ti-6Al-4V (β-STOA)

<u>Accomplishment</u>: Sikorsky has been contacted to obtain the titanium alloy material to conduct small surface-crack and/or S-N and small-crack tests.



Remaining material unavailable

Requested titanium alloy forging of same composition and heat treatment

Titanium alloy forgings blanks obtained from Sikorsky on previous FAA grant

Future Plans

- **Near Future**
  - Complete small-crack review document
  - Continue literature search for large-crack data
  - Complete stress analyses on large-crack specimen
  - Machine large-crack 2024-T3 and 7075-T6 specimens
- **Future**
  - Conduct further stress analyses on small-crack specimen(s)
  - Obtain titanium (β-STOA) alloy forging(s) from Sikorsky
  - Obtain 7050-T7451 alloy plate from Alcoa (Bucci)
  - Finalize search and selection of additional materials